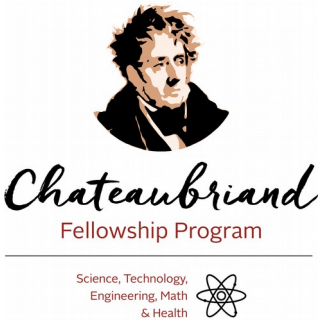
Search for the dimuon decay of the Higgs boson with the ATLAS experiment



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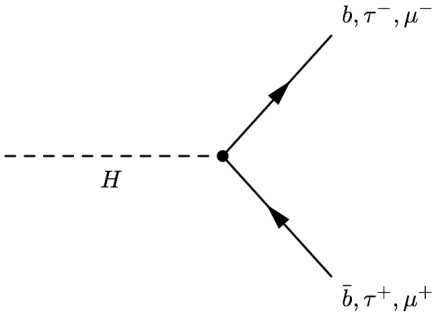
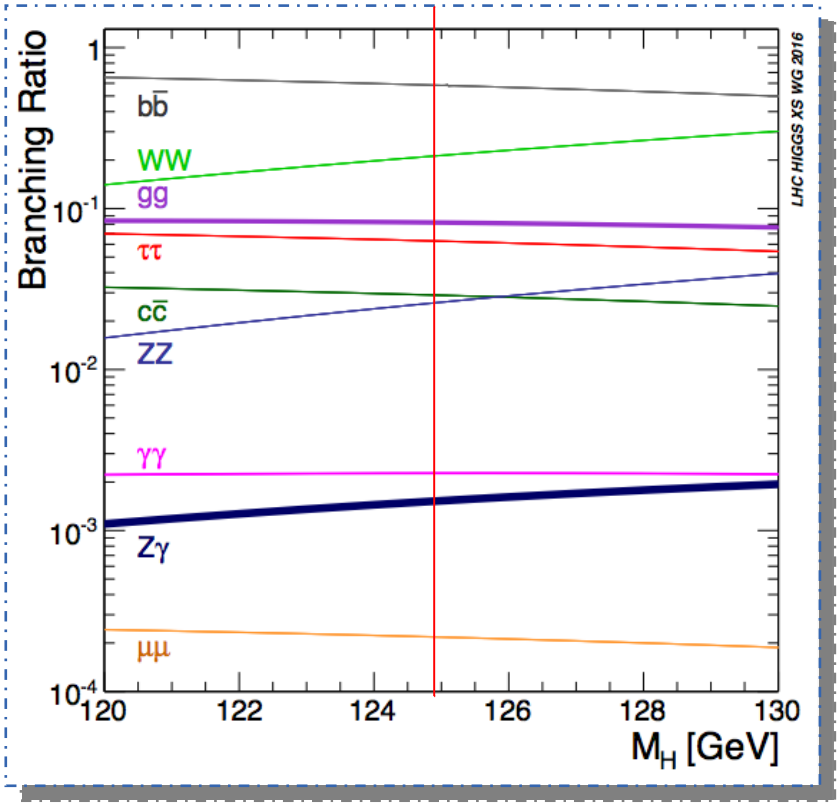
DPF, Fermilab 2017

Motivation



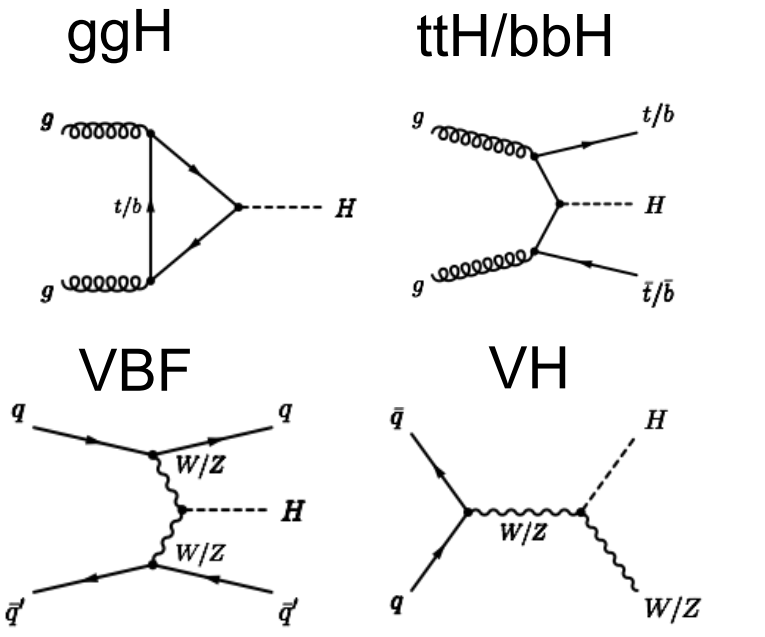
- $H \rightarrow \mu\mu$ is a rare decay with a clean final state signature. But there are very large irreducible backgrounds from Z and diboson – very challenging detection
- Measure the SM Higgs Yukawa coupling to the 2nd generation fermions
- High luminosity of LHC run 2 will offer greatly increased sensitivity
- Paper based on 2015+2016 data sets (at 13 TeV) has been recently accepted to PRL on June 20, 2017 **arXiv:1705.0458**



$Br(H \rightarrow \mu\mu) = 2.2 \times 10^{-4}$

Higgs production at the LHC

- Production mechanism are shown in right diagrams
- Search for H→μμ has been carried out using ggH and VBF production modes
- We are now developing the framework by including the VH and ttH/bbH production modes



10.23731/CYRM-2017-002

Mode	ggH	VBF	ZH	WH	bbH	ttH
σ(H) (13 TeV) [pb]	43.92	3.75	0.975	1.38	0.512	0.509
N_{event} (300 fb^{-1}) for H→μμ	2898	247	64.3	91.1	33.8	33.6

Data and MC Samples

- **Data used in analysis**
  - 13TeV, 36.1 fb^{-1} (2015 + 2016 datasets)
- **Monte-Carlo samples are used to:**
  - Develop categorization
  - Develop background model
  - Develop signal model
  - Train BDT to extract signal
  - Estimate experimental uncertainty
- **Backgrounds considered:**
  - Diboson (ZZ, ZW, WW) production
  - Single top and ttbar production
  - Drell-Yan (Z+jets, W+jets)

Process	Generator/Parton Shower
VBF	Powheg/Pythia 8
ggH	Powheg/Pythia 8
ZH	Powheg/Pythia 8
WH	Powheg/Pythia 8
Drell-Yan	Madgraph/Pythia 8
$t\bar{t}$/single top	Sherpa
Diboson	Sherpa

Muon Selection

Muon selection	
ID hits	$n_{hits}^{pixel} > 0, n_{hits}^{SCT} > 4,$ $n_{holes}^{pixel+SCT} < 3, n_{hits+outliers}^{pixel+TRT} > 5,$ $n_{hits}^{TRT} > 0.1 \times n_{hits+outliers}^{TRT}$ for $0.1 < \lvert\eta\rvert < 1.9$
MDT/CSC hits	$n_{layers} > 1$ for $\lvert\eta\rvert > 0.1$, $n_{layers} >= 1$ and $n_{layerholes} < 2$ for $\lvert\eta\rvert < 0.1$ where hit layers are defined for layers in MDT or CSC with at least three hits.
Track Quality	q/p significance < 7
Pt	Pt>15GeV
η	$\lvert\eta\rvert < 2.5$
Isolation	LooseTrackOnly
Impact parameter d	$\lvert d_0^{BL} significance\rvert < 3$
Impact parameter z	$\lvert z_0^{PV} \times \sin(\theta)\rvert < 0.5mm$

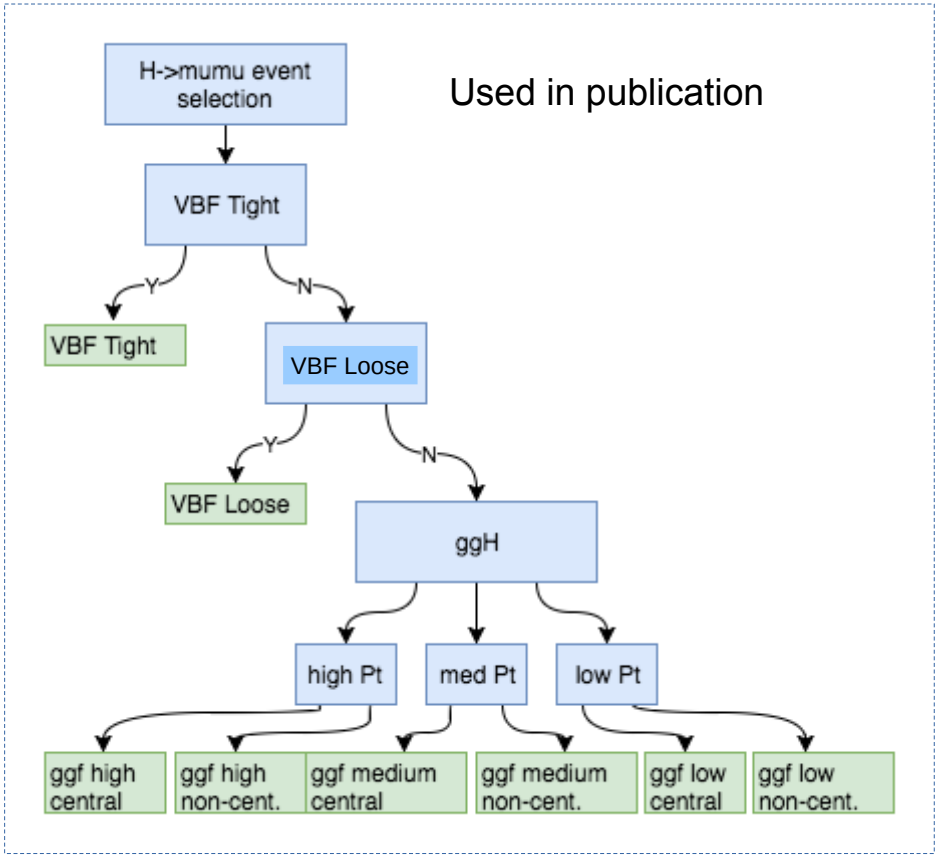
H→ μμ Event Pre-selection

- Dimuon event selection
  - Select isolated muon pT>24 (26) GeV in 2015 (2016)
  - |η| of muon < 2.5
  - Dimuon pair (μ+,μ-) with invariant mass in the range [**110-160] GeV**
  - The dimuon momentum balance in H-rest frame

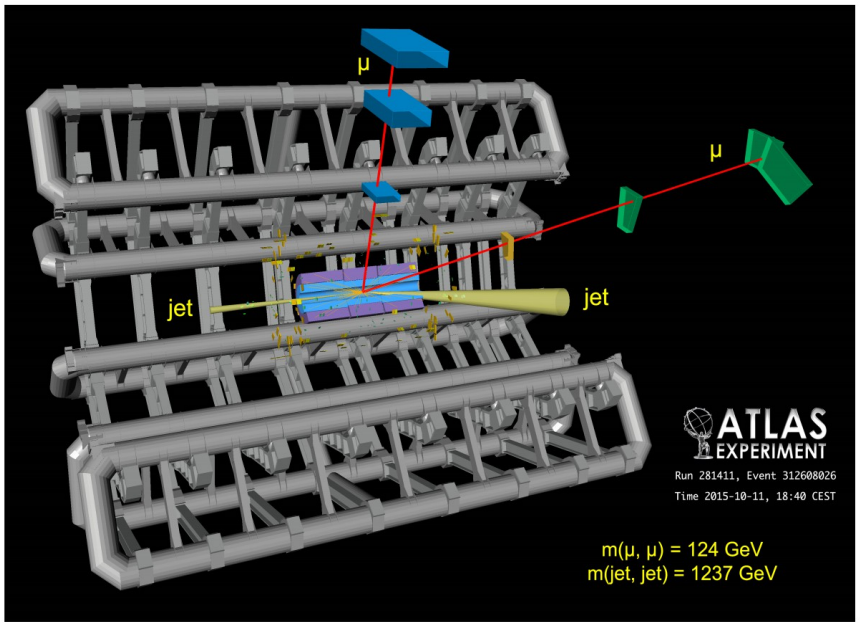
$$\frac{|\vec{p}^{+} + \vec{p}^{-}|}{|p^{+}| + |p^{-}|} < 0.05$$

- Based on MC data, the pre-selection efficiencies are:
  - 57% efficient for ggH
  - 59% efficient for VBF
  - 51% efficient for both WH and ZH

Event Categorization

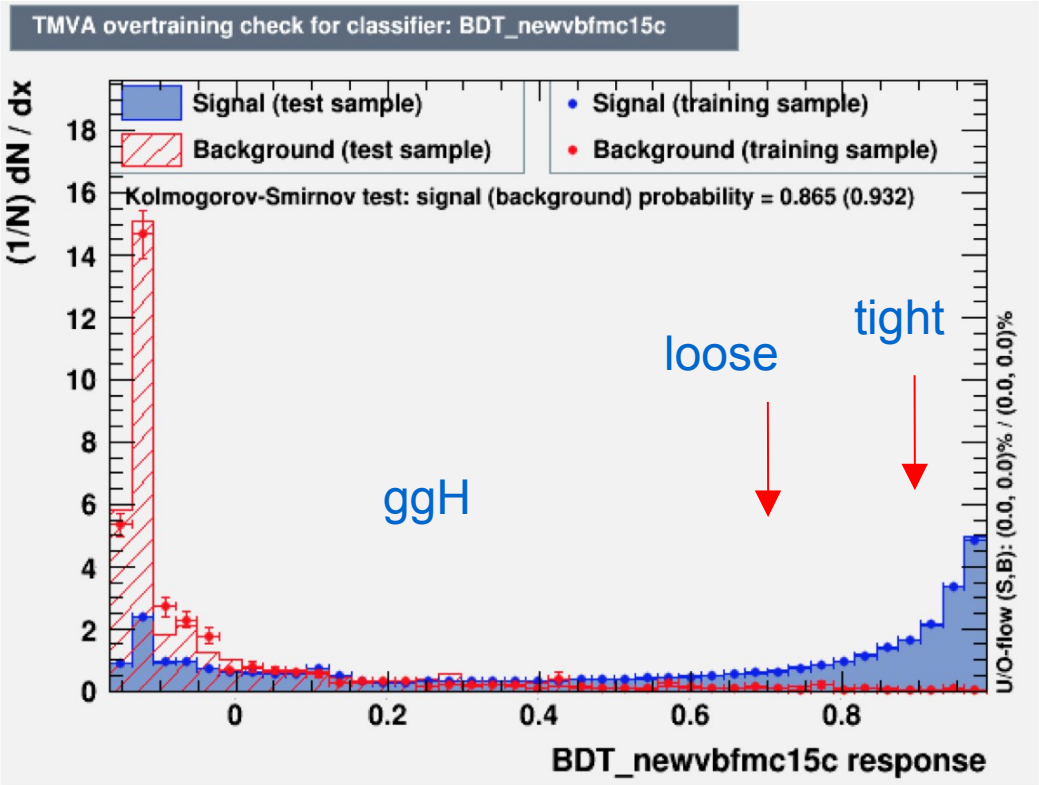


- VBF - BDT discriminant variable (new in Run 2)
  - VBF tight (BDT score > 0.9)
  - VBF loose (BDT score > 0.7)
- ggH - kinematic cuts
  - central or non-central dimuon
  - pT bins: low, medium, high



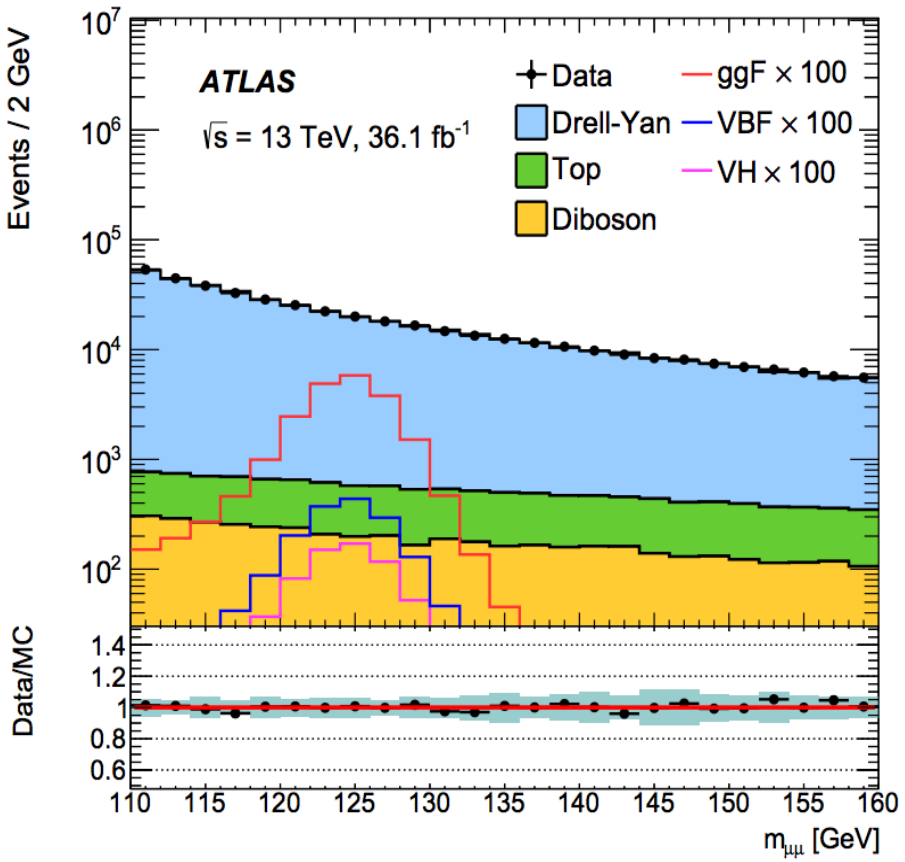
VBF BDT Discriminant Variable

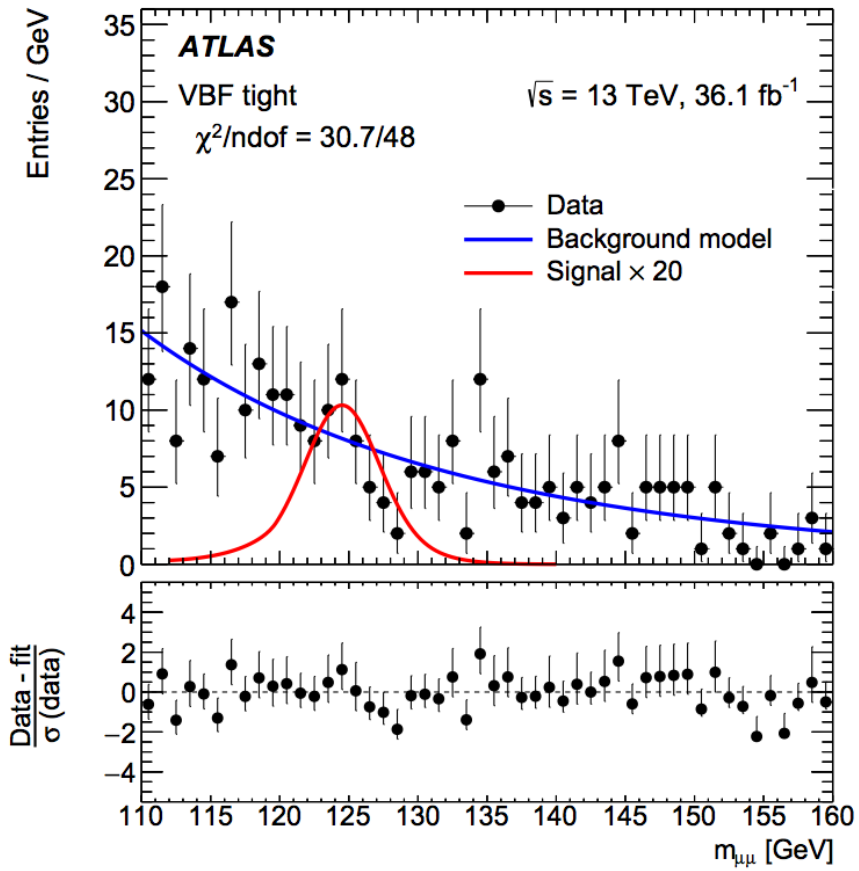
Rank	Variable	Importance
1	$\Delta\eta_{jj}$	2.4e-1
2	m_{jj}	2.7e-1
3	$p_T^{\mu\mu}$	1.3e-1
4	ΔR_{jj}	9.2e-2
5	p_T^{jj}	5.4e-2
6	$y_{\mu\mu j1}$	5.2e-2
7	centrality	4.7e-2
8	Ht	4.3e-2
9	$p_T^{\mu\mu jj}$	4.0e-2
10	E_T^{miss}	3.3e-2
11	$y_{\mu\mu jj}$	2,7e-2
12	$P_T^{\mu\mu j1}$	2.3e-2
13	$P_T^{\mu\mu j2}$	1.9e-2
14	$y_{\mu\mu j2}$	1.6e-2



H→μμ detection from VBF/ggH

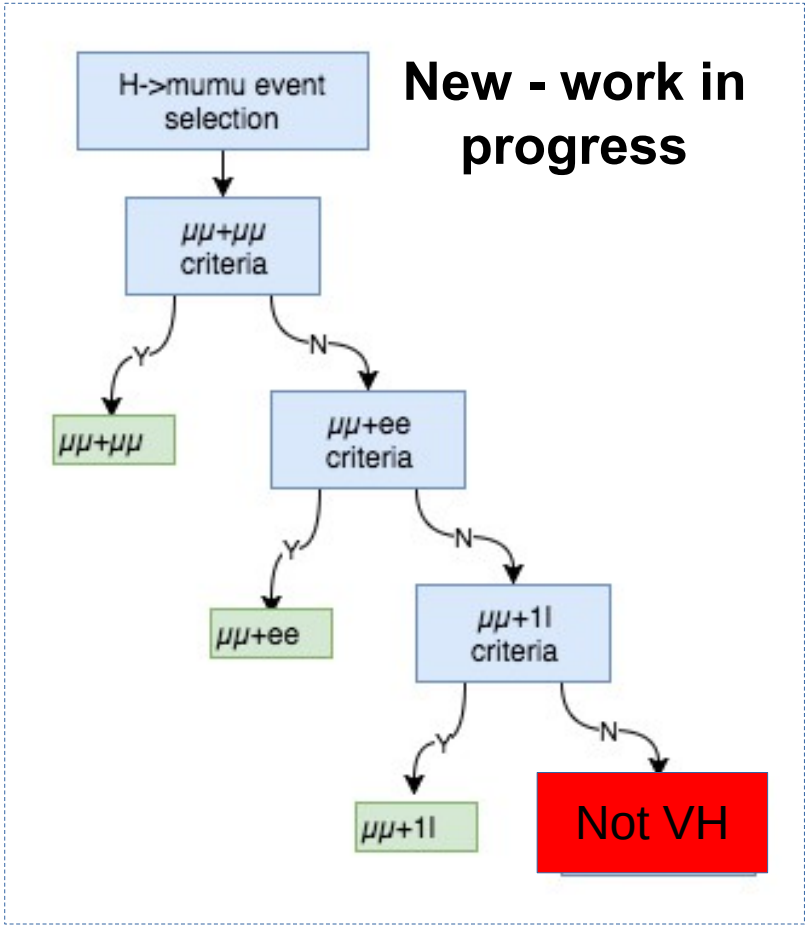
[arXiv:1705.04582]





The upper limit on the cross-section times branching ratio is **3.0** times the Standard Model prediction at the 95% confidence level

Event Categorization



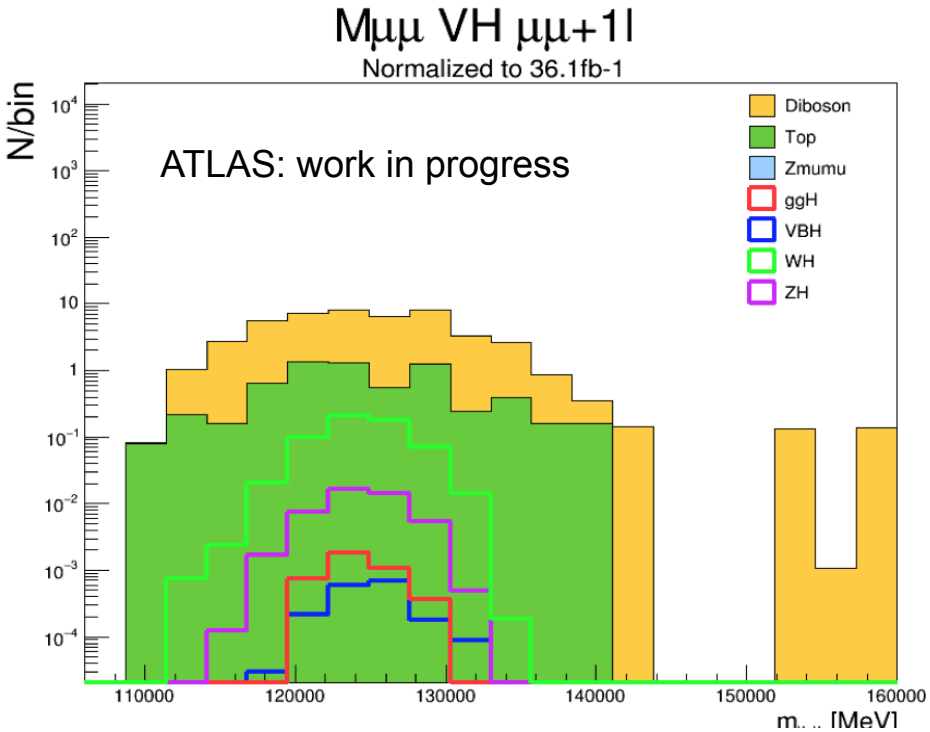
- VH - kinematic cuts
  - μμ+μμ for H→μμ, Z→μμ
  - μμ+ee for H→μμ, Z→ee
  - μμ+1l for H→μμ, W→nl
  - Categories for VH→jj+μμ and ZH→νν+μμ are being studies, but these events have low S/B

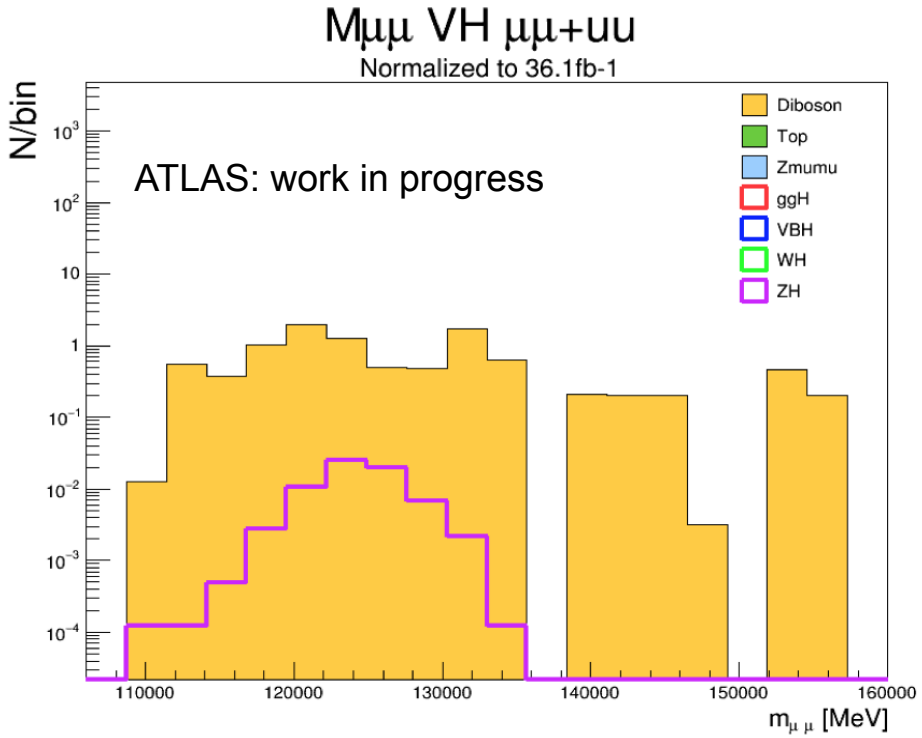
New VH Categories

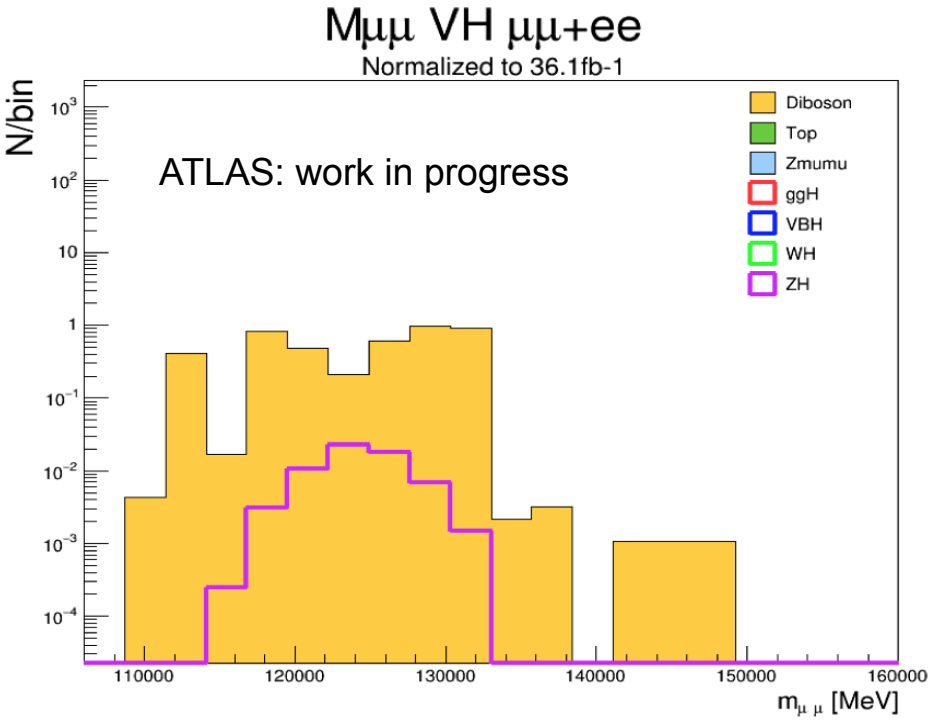
Category	Requirement
$VH \to \mu\mu + \mu\mu$	additional dimuon pair one dimuon mass in Higgs range (110-160 GeV) simultaneous dimuon mass in Z range (75-110 GeV)
$VH \to ee + \mu\mu$	additional dielectron pair one dielectron pair in Z range
$VH \to e + \mu\mu$	additional electron No b-jet in event $40 < M_t^{e,MET} < 200\text{GeV}$ $P_t^e > 30\text{GeV}$
$VH \to \mu + \mu\mu$	additional muon No dimuon pair in Z range One dimuon pair in Higgs range Third muon ($\mu*$) with $P_t^{\mu*} > 30\text{GeV}$ No b-jet in event $40 < M_t^{\mu*,MET} < 200\text{GeV}$
$VH \to dijets + \mu\mu$	Two or more jets in event For both jets, $\lvert\eta\rvert < 3$ $\Delta\phi_{H,dijet} > 2$ $61 < m_{jj} < 121$ GeV
$VH \to MET + \mu\mu$	Zero additional leptons $\Delta\phi_{H,met} > 2$ $MET > 80\text{GeV}$ No b-jet in event

New VH Category

Invariant mass distributions of the most sensitive VH categories







Compare Sensitivities

- Combined sensitivity at 36.1fb^{-1}

Results with ggH & VBF (published)

	S	B	$S/\sqrt{B}$	FWHM	Data
Central low $p_T^{\mu\mu}$	11	8000	0.12	5.6 GeV	7885
Non-central low $p_T^{\mu\mu}$	32	38000	0.16	7.0 GeV	38777
Central medium $p_T^{\mu\mu}$	23	6400	0.29	5.7 GeV	6585
Non-central medium $p_T^{\mu\mu}$	66	31000	0.37	7.1 GeV	31291
Central high $p_T^{\mu\mu}$	16	3300	0.28	6.3 GeV	3160
Non-central high $p_T^{\mu\mu}$	40	13000	0.35	7.7 GeV	12829
VBF loose	3.4	260	0.21	7.6 GeV	274
VBF tight	3.4	78	0.38	7.5 GeV	79

Combined significance: 0.806 σ

New results: add VH Working in progress

Category	**Signal**	**Background**	S/B	$S/\sqrt{B}$
VH $\mu\mu$+ee	0.06	2.30	0.0253	0.0384
VH $\mu\mu$+$\mu\mu$	0.06	4.21	0.0149	0.0306
VH $\mu\mu$+1l	0.61	30.12	0.0201	0.1106
VBF tight	4.01	113.58	0.0353	0.3767
VBF loose	4.01	337.66	0.0119	0.2180
ggH cental low pT	12.27	11773.04	0.0010	0.1131
ggH cental mid pT	28.29	10674.04	0.0026	0.2738
ggH cental high pT	22.57	6337.76	0.0036	0.2835
ggH non-central low pT	31.86	41451.21	0.0008	0.1565
ggH non-central mid pT	72.87	38152.81	0.0019	0.3731
ggH non-central high pT	51.83	19241.19	0.0027	0.3736

Combined significance: 0.822 σ

Summary

- The recent ATLAS published upper limit on the **cross-section times branching ratio** for H→μμ is 3.0 times the SM prediction at the 95% C.L.

- **Continue work in Run 2 data analysis**
  - Include the VH and ttH categories in analysis
  - Further train BDTs for VH and ttH categories
  - Optimize priority of new categories

- **Prospect:**
  - The expected significance (S/sqrt(B+S)) of H→μμ detection is 2.4σ (or better) for 300 fb^{-1}

Thanks to Michigan, LAL Orsay, DOE, OST

Backups

Physics object selection

Electron selection	
Identification selection	imedium
Pt	Pt>7GeV
η	$\lvert\eta\rvert < 2.47$, $1.37 < \lvert\eta\rvert < 1.52$
Quality	Not "BADCLUSTERELECTRON"
Isolation	LooseTrackOnly
Impact parameter d	$\lvert d_0^{BL} signifigance\rvert < 5$
Impact parameter z	$\lvert z_0^{PV} \times \sin\theta\rvert < 0.5mm$

Muon selection	
ID hits	$n_{hits}^{pixel} > 0, n_{hits}^{SCT} > 4,$ $n_{holes}^{pixel+SCT} < 3, n_{hits+outliers}^{pixel+TRT} > 5,$ $n_{hits}^{TRT} > 0.1 \times n_{hits+outliers}^{TRT}$ for $0.1 < \lvert\eta\rvert < 1.9$
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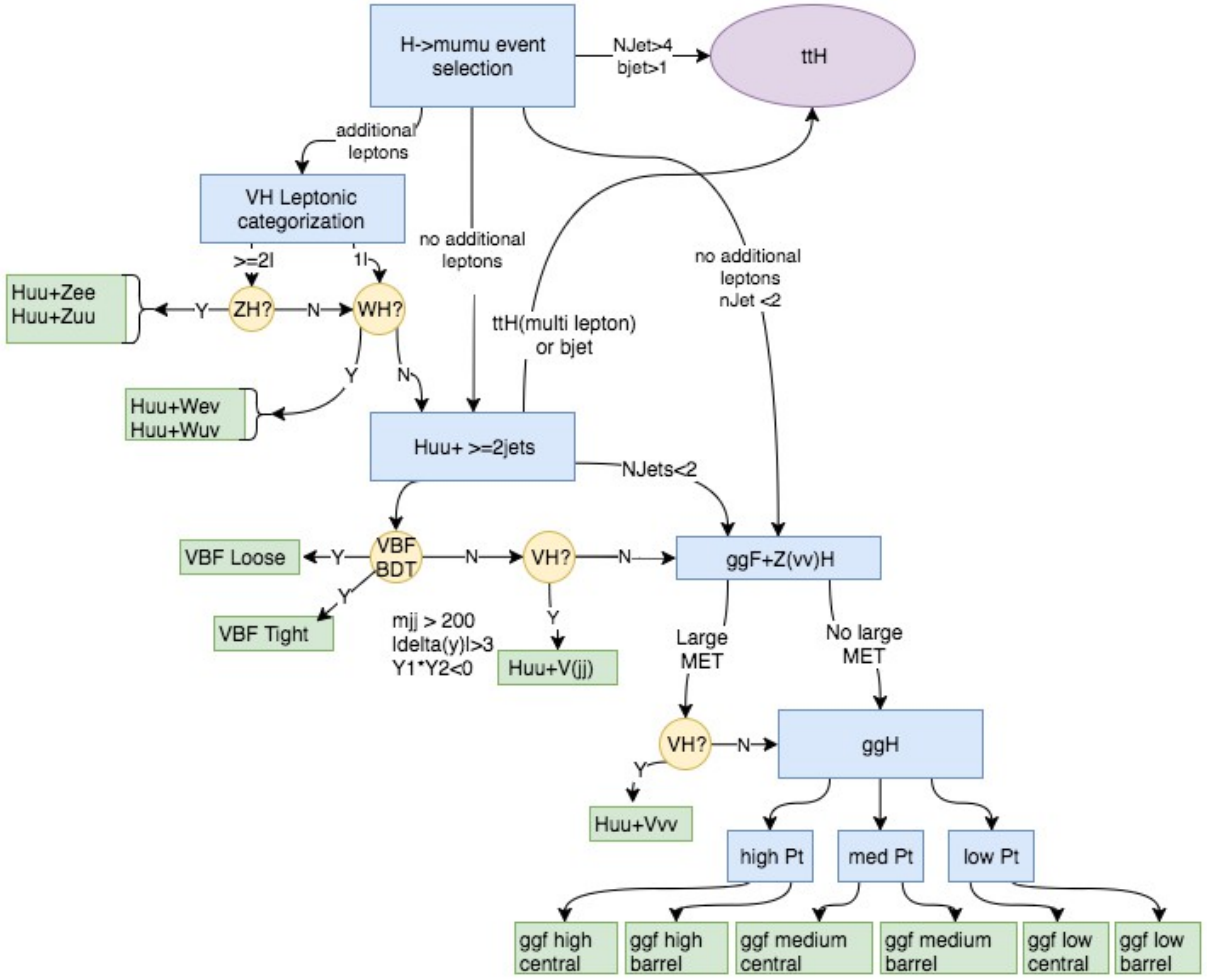
Impact parameter z	$\lvert z_0^{PV} \times \sin(\theta)\rvert < 0.5mm$

Jets are built using the anti-kt algorithm

Jet selection	
Identification selection	imedium
Pt	Pt>25GeV for $\lvert\eta\rvert < 2.4$ and Pt>30GeV for $2.4 < \lvert\eta\rvert < 4.5$
Cleaning	Not BadLoose
Jet Vertex Tagger	JVT>0.59 for Pt<60GeV and $\eta < 2.4$
b-jet	Pass MC2c10 60%

Backup - combining VH into VBF/ggH



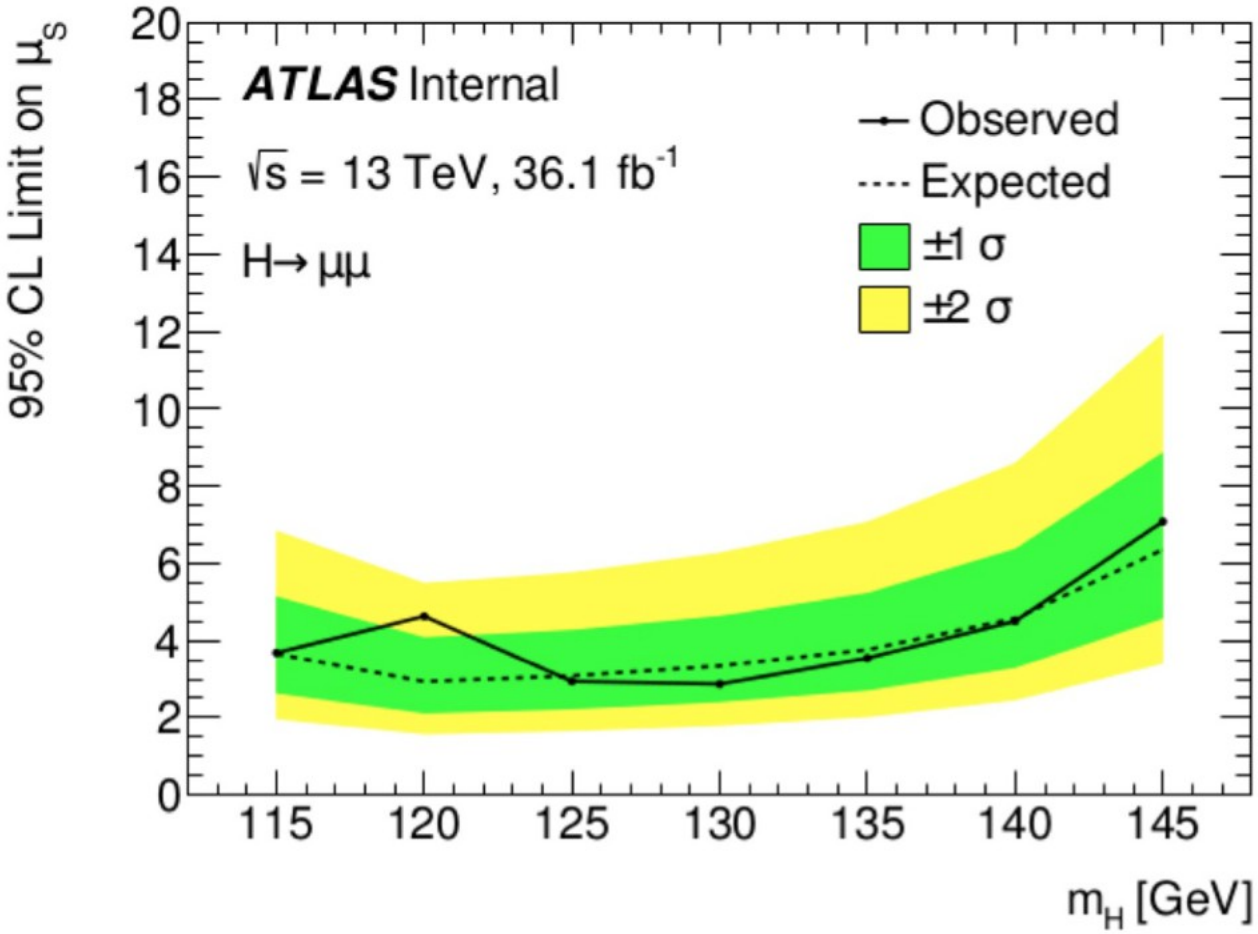


Figure 11: Observed and expected 95% CL limits on signal strength using 13 TeV data.